N91-14927

SMALL SCALE VARIATIONS OF ABUNDANCES OF TRANSIENTLY HEATED GRAINS IN MOLECULAR CLOUDS

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IRAS images of a variety of fragments in nearby molecular clouds show that the energy distribution of their IR emission varies widely from cloud to cloud and from place to place within a given cloud (see Figure 1 and other examples in Puget, 1988). These variations at small scale are all the more unexpected that the colors of the IR emission of cold material differ very little at large scale: the colors of the cirrus emission above the 3kpc molecular ring are the same as those of the cirrus emission in the solar neighborhood (Pérault et al., 1988).

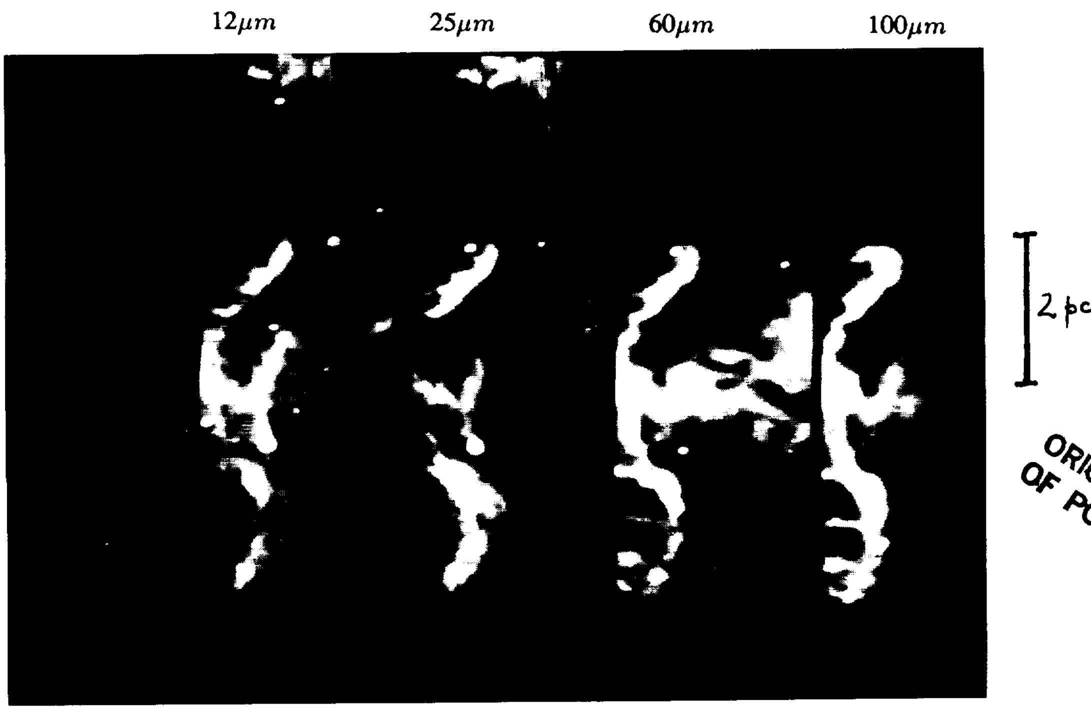

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Figure 1.: *Molecular filament near ζ Oph. Different morphologies in the four IRAS bands illustrate color differences*

To quantitatively study these variations, we obtained 12μm, 60μm and 100μm brightnesses of small areas centered at different positions within the set of clouds and complexes listed in the Table. The range of observed $I_\nu(12\mu m)/I_\nu(100\mu m)$ colors is given for each cloud. Variations by an order of magnitude are found in most clouds. Variations by a factor 2 to 3 are observed within a cloud on scales as small as 0.5pc, the resolution of our study. Maximum observed $I_\nu(12\mu m)/I_\nu(100\mu m)$ values are roughly 3 to 4 times larger than the average value obtained by Boulanger and Pérault (1988) for the nearby interstellar medium; the lowest upper limits are more than a factor of 10 lower than this value. For a subset of our measurements, we derived an estimate of the visual extinction from ^{13}CO observations or star counts. This estimate enables us to measure the $100\mu m$ emissivity per proton. The $I_\nu(12\mu m)/I_\nu(100\mu m)$ color is plotted against the $100\mu m$ brightness, the $100\mu m/A_v$ ratio and the $I_\nu(60\mu m)/I_\nu(100\mu m)$ color in figures 2, 3 and 4. In figure 4, we separated the data in two families on the basis of their $100\mu m$ brightness: on the one hand, clouds or fragments of clouds with $I_\nu(100\mu m) < 10MJy/sr$ which show little extinction ($A_v < 1mag$) on optical plates (translucent clouds), on the other hand dark clouds brighter at $100\mu m$ and more opaque in the visible ($A_v > 2mag$).

Table

Cloud of complex	Size (pc)	$I_\nu(12\mu m)/I_\nu(100\mu m)$	$A_v(mag)^{(*)}$	Type of cloud
Taurus Auriga Perseus	50	<0.015-0.12	1.5-6	dark
Ophiuchus filaments	10	0.02-0.13	1-3	dark
Ophiuchus core	2	<0.01-0.1	5-50	dark
Chamaeleon	10	<0.003-0.16	0.5-3	translucent/dark
Ursa Major	10	0.035-0.15	0.1-1	translucent
High Latitude Clouds	5	<0.02-0.16	0.1-1	translucent

(*). *Range of visual extinction at an angular scale of a few arcmin.*

I. Observational facts.

The elements directly derived from observational data are the following:

1) large variations of the $I_\nu(12\mu m)/I_\nu(100\mu m)$ color are found from one cloud to another and within molecular clouds on scales as small as the resolution of our study, $\sim 0.5pc$ (Table),

2) the amplitude of the variations is not related to the nature of the clouds. Dark and translucent clouds exhibit a similar range of $I_\nu(12\mu m)/I_\nu(100\mu m)$ colors (Figure 2). These clouds are all molecular or closely associated with a molecular cloud. There is presently no evidence for a similar scatter among isolated HI clouds: for comparison, colors obtained for a small sample of atomic clouds are also plotted in figure 2,

3) color variations do not depend on the intensity of the heating radiation field (Figure 3). In this figure, we use the $100\mu m/A_v$ ratio as an indicator of the average intensity of the radiation field along the line of sight. This implicitely assumes that the absorptivity of large grains (emitters of the $100\mu m$) and the fraction of the total energy they radiate in the $100\mu m$ band do not vary much within our sample of clouds. The latter condition is met for an equilibrium temperature of large grains between 18K and 32K assuming an emissivity law in λ^{-2}.

4) dark clouds show a correlation between $I_\nu(12\mu m)/I_\nu(100\mu m)$ and $I_\nu(60\mu m)/I_\nu(100\mu m)$ colors while translucent clouds do not (Figure 4). The difference between the two families suggests that the size

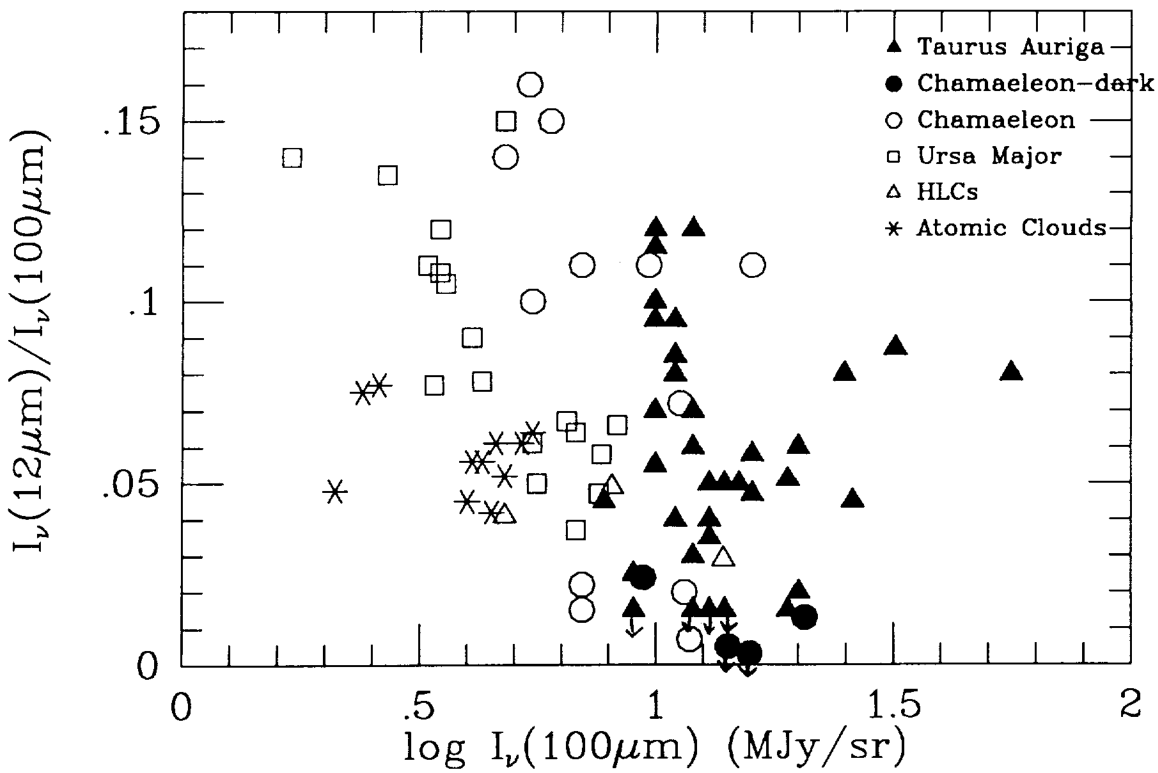

Figure 2.: *$I_\nu(12\mu m)/I_\nu(100\mu m)$ color versus 100μm brightness. The symbols are solid for dark clouds and open for translucent clouds.*

distribution of the small particles (the radiation of which is caused by temperature fluctuations) is not the same for the two sets of clouds. In the dark clouds, the observed correlation indicates that (i) part of the 60μm emission is due to small grains and (ii) what makes the 12μm emission vary, simultaneously affects the 60μm emission. In the other family, either there is no contribution of small grains to the 60μm emission or there is a contribution but no link between the particles responsible for the 12μm and 60μm emission.

II. Elements of interpretation.

The color variations seen here cannot be accounted for by the 12μm limb brightening of the kind discussed by Beichman et al. (1988) for the B5 cloud or by Puget (1988) at the edges of filaments and fragments in the Ophiuchus cloud. In these cases, part of the effect is due to the reddening of the spectrum of the heating radiation as the depth within the cloud increases: in the outer layers most of the heating comes from UV photons, in the inner layers dust is heated by visible and near-IR light. The amplitude of the variations reported on here cannot be reproduced by any reasonable density structure of the cloud (see models in Beichman et al., 1988).

We thus conclude that large variations of the abundances of small particles with respect to those of the large grains responsible for the 100μm emission are required to explain the observed color variations and that these abundances have to vary by large factors: an order of magnitude from cloud to cloud and 2 to 3 from place to place within one cloud.

Several physical mechanisms may be invoked to account for these variations at small scale. Agglomeration between the smallest particles and/or condensation on large grains, desorption of small particles and large molecules from the surface of large grains triggered either by UV photons or via collisions with the gas, inhomogeneities possibly driven by the disordered velocity field within clouds or shock chemistry.

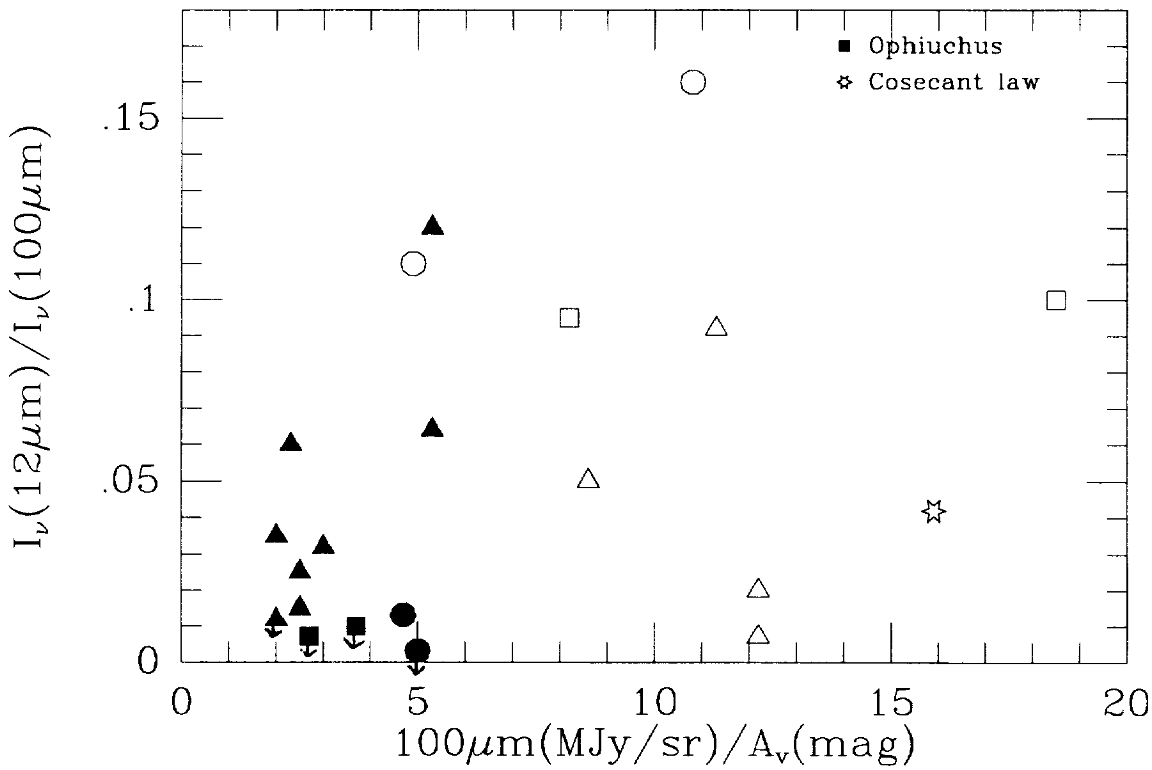

Figure 3.: *$I_\nu(12\mu m)/I_\nu(100\mu m)$ versus $100\mu m/A_v$ for the subset of measurements for which visual extinction has been estimated. Unspecified symbols are the same as in figure 2.*

Any interpretation faces the problem of the short mixing timescale, $\tau \sim 5\,10^5 yr$ over $\sim 0.5pc$ for internal cloud velocities of the order of $1km/s$.

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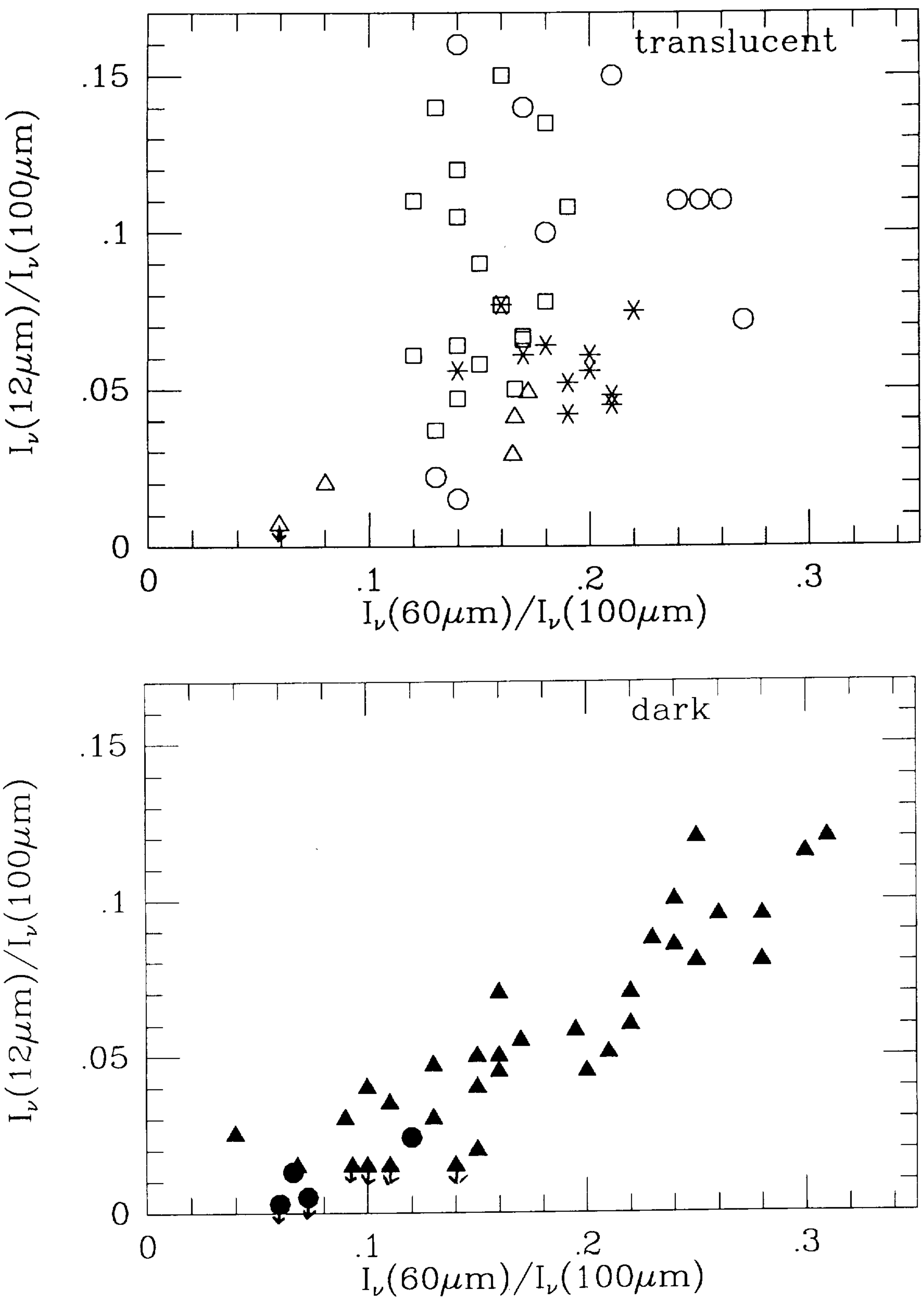

Figure 4.: $I_\nu(12\mu m)/I_\nu(100\mu m)$ *versus* $I_\nu(60\mu m)/I_\nu(100\mu m)$ *for the two families of clouds. Symbols are the same as in figure 2.*